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INVESTIGATION OF THE APPLICATION OF HCMM THERMAL DATA TO SNOW HYDROLOGY

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1. INTRODUCTION

1.1 Objectives of Investigation

The objectives of the investigation of the application of HCMM thermal data to snow hydrology (HCMM Investigation No. 036) are as follows:

(1) determine practical utility of HCMM thermal IR data to establish distribution of snow cover and determine accuracy of temperature measurements;

   a. determine accuracy of surface temperatures acquired through use of HCMM thermal IR measurements,

   b. determine relative resolution utility between VHRR and HCMM for thermal IR measurements, and

   c. specifically delineate and quantify the problems involved with measuring snow temperature from space and relate them to present and planned earth observing satellite systems. This objective will take into consideration and utilize the capability of HCMM for day and night thermal measurements over appropriate sites and the satellite's eight-day repeat cycle;

(2) determine if and how HCMM measurements can be factored in with Landsat data into an overall snow hydrology program related directly to snowmelt runoff prediction; and

(3) develop an approach to automated data processing of combined visible and thermal infrared satellite acquired data to provide information of interest and use to the snow hydrologist.

1.2 Anticipated Results

The primary anticipated result of the proposed investigation is the development of improved techniques for the mapping and analysis of snow cover using spacecraft-acquired data. The results will provide an evaluation of the usefulness of high resolution thermal infrared data for snow mapping and for input to snowmelt prediction programs; and will provide a better understanding of the relationships between the measured

temperature values and such factors as type of snow, snow depth, type of terrain, and vegetation. The mapping and analysis techniques can then be applied to the automatic processing of data from future spacecraft systems, and will eventually enable snow survey, which is a vital part of water resources management, to be accomplished on a more cost-effective basis.

2. ACCOMPLISHMENTS DURING REPORTING PERIOD

2.1 Summary of Data Sample

a. HCMM Imagery and CCT's

During this reporting period, additional HCMM imagery and CCT's have been received. To date, the total number of scenes for which images have been received for this investigation is more than 150. Of this data sample, many scenes are not useable because of substantial cloud cover, data noise, or the area of coverage being outside the specified study areas. However, several good-quality, cloud-free scenes have now been accumulated for the two primary study areas: Arizona (Salt-Verde watershed area), and Sierras in California (Kings River Basin area). The scenes for these two study areas for which CCT's have been acquired are listed in Table 1.

Images and CCT's for one day/night registered pair of HCMM scenes were received at the end of the reporting period. These data are for the 36-hour sequential coverage of the Sierras for 30-31 May 1978.

b. U-2 Data

Data are on-hand for three supporting U-2 aircraft day/night missions over the Sierras study area and one day/night mission over the Arizona study area. A summary of the U-2 data is as follows:

<u>Sierras Test Area (Kings River Basin)</u>

a. HCMR Instrument

day/night mission (flights 78-033/034)
31 May/1 June 1978

day/night mission (flights 78-035/036)
19/20 July 1978

TABLE 1

HCMM DATA SAMPLE FOR PRIMARY STUDY AREAS

Arizona Test Area

Date	Type of Data
9 Feb 79	Day VIS
9 Feb 79	Day IR
15 Feb 79	Day VIS
15 Feb 79	Day IR
24 Mar 79	Day VIS
24 Mar 79	Day IR
4 Apr 79	Day VIS
4 Apr 79	Day IR
15 Apr 79	Day VIS
15 Apr 79	Day IR

Sierras Test Area

Date	Type of Data
29 May 78	Night IR
30 May 78	Night IR
30 May 78	Day IR
31 May 78	Day IR
17 Jul 78	Night IR
17 Jul 78	Day IR
20 Jan 79	Night IR
20 Jan 79	Day IR
3 Apr 79	Night IR
4 Apr 79	Night IR
5 Apr 79	Day IR

b. High Altitude Multispectral Scanner

night/day mission (flights 79-029/030)
4 April 1979

Arizona Test Area (Salt/Verde Watershed)

High Altitude Multispectral Scanner

night/day mission (flights 79-029/030)
4 April 1979

c. Ground Truth Information

Ground truth information for the Sierras and Airzona study areas is being derived from climatological data summaries, aerial snow survey charts, snow course measurements, SNOTEL data, and other ground-based observations from sources such as the Salt River Project office. The HCMM thermal patterns are also being compared with the snow extent mapped from the visible channel and with other satellite data, including Landsat, NOAA-VHRR (and AVHRR), and GOES.

2.2 Processing of HCMM Digital Data

Two programs have been developed at ERT to process HCMM thermal infrared digital data (CCT's). One program is designed to print out the data for hand analysis; the second program is designed to produce automated contour mapping. The two programs are described below and shown schematically in Figure 1.

a. Print Program

The "print" program was developed to (a) convert HCMM digital counts within selected areas to degrees Celsius, and (b) convert the temperatures into alpha-numeric characters, which are printed out scan line by scan line. The resulting printout is suitable for hand analysis.

b. Contour Program

The "contour" program was developed to extract and display specified temperature values over selected areas of the HCMM image. This unique program uses a raster to vector conversion to compute and output exact pixel (x) and scanline (y) positions of the desired temperature

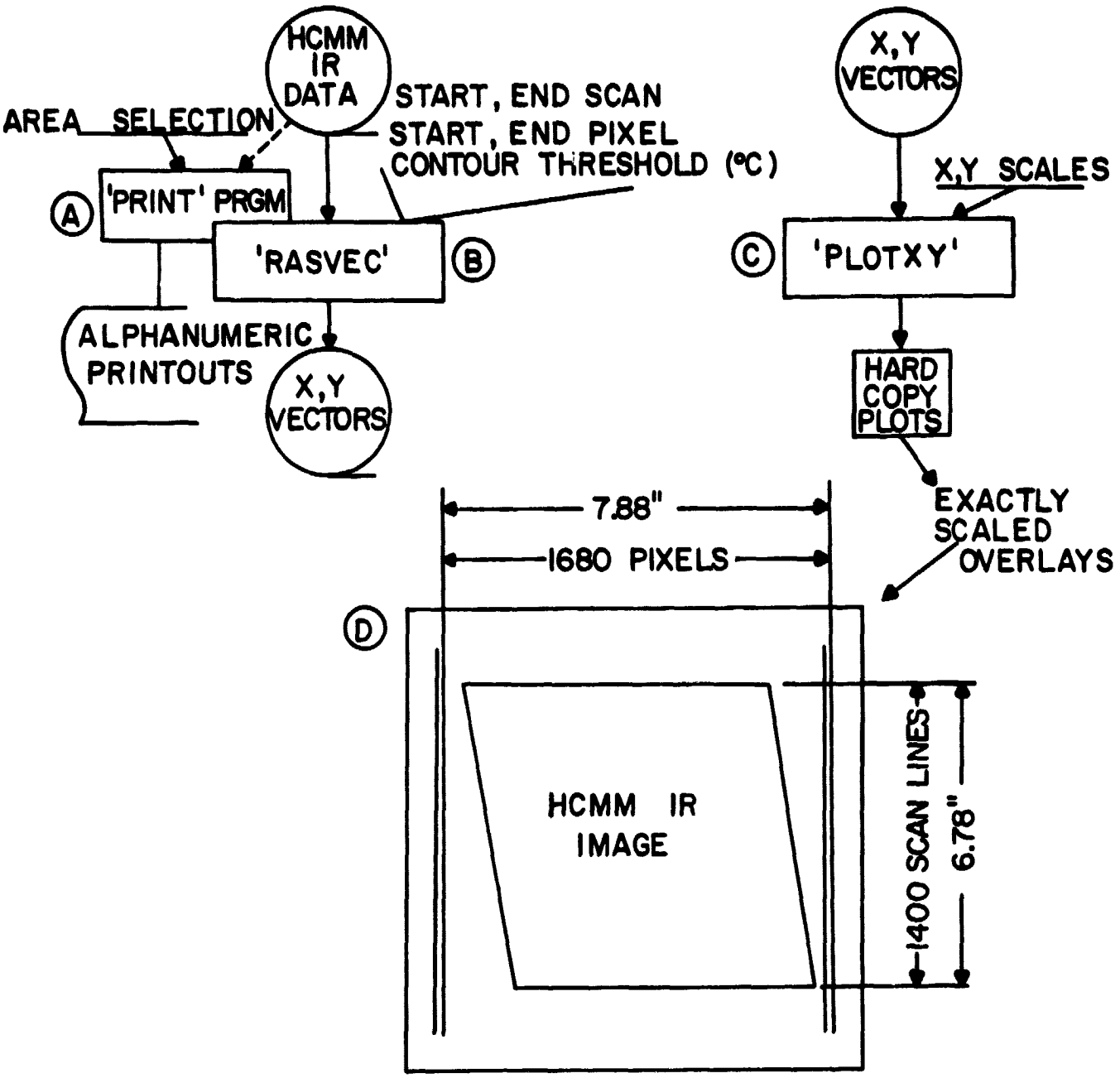

Figure 1 Schematic Diagram of Print and Automated Contouring Programs for HCMM Thermal IR CCT's

values. A plot program then drives a CRT plotter for displaying the vectors created by the raster to vector program at the exact scale of the HCMM imagery. Registration lines are also plotted to be used for registration of the contours within the image; it is possible, therefore, to overlay the thermal contours on the visible image.

The system to produce the automated contouring of HCMM thermal data is shown in Figure 1. The structure of a typical HCMM image showing the critical dimensions used for scaling the plotted vectors is indicated. Further modifications to the "RASVEC" program are intended to process the data from the U-2 High Altitude Multispectral Scanner in the same manner.

2.3 Data Analysis

Analysis of the daytime cases for the Arizona study area for the February to April 1979 period is in progress. There was no nighttime HCMM coverage during this period. The preliminary results of the analysis are given in Section 7 "Significant Results".

The analysis for the Sierras study area has been concentrated on the 29-31 May 1978 case, because of the good day/night sequential HCMM coverage. The preliminary results are given in Section 7.

3. PROBLEMS

As discussed in the previous progress report, additional funds would be needed to work with any significant amount of data from the U-2 High Altitude Multispectral Scanner. A further assessment of the overall financial status of the contract was made early in this reporting period. As a result, a request for additional funds and an extension in time was submitted to the HCMM Investigations Office.

Late in the reporting period a contract modification was negotiated. The additional funds will permit the investigation to be completed and meet all originally proposed objectives. Under the revised contract schedule, with the time extension, the draft final report will be due 23 September 1980.

4. PLANS FOR NEXT REPORTING PERIOD

The analysis of the HCMM and supporting data will be continued for the two primary study areas (central Arizona mountains and Sierra Nevada in California). All data needed for the analysis, except for some of the day/night temperature difference data, are now on hand. We anticipate that the additional day/night data will be received early in the next reporting period.

The analysis procedures described in earlier progress reports will be followed. For the Arizona study area, emphasis will be on examining the behavior of the snow surface temperature as the snow cover depletes during the spring melt season (no nighttime HCMM data were available for the sample period). For the Sierras, considerable attention will be given to examining the relationship between the day/night temperature difference and the snow conditions. The analysis of the May 1978 case will be completed, and the analysis of other cases (July 1978 and April 1979) will be undertaken. For both study areas, attempts will be made to establish an external calibration of the HCMM thermal measurements through comparison with the U-2 data and with ground-based measurements. Atmospheric corrections will be applied to the HCMM data using, at least for some cases, both the RADTRA program and the LOWTRAN program.

5. TRAVEL

During this reporting period, the Principal Investigator attended the HCMM Experimenters Team (HET) meeting in Ispra, Italy, on 26-28 March. A presentation on the status of the investigation was given at the meeting. The meeting was very worthwhile because it gave the HET members the opportunity to become familiar with the European investigations being carried out under the Tellus Program and to evaluate the utility of the HCMM data to these investigations. Future cooperative US-European space programs were also discussed at the meeting.

6. PUBLICATIONS

No material related to this investigation was published during this reporting period.

7. SIGNIFICANT RESULTS

7.1 Arizona Study Area

The HCMM digital thermal data are being analyzed for the Salt-Verde Watershed area of central Arizona (see map in Figure 2) for the daytime passes of 9 and 15 February, 24 March, and 4 and 15 April 1979. The observations on these dates show a gradual depletion of the snow cover in the watershed (and in the Little Colorado Watershed to the north) from a maximum in early February to a nearly complete disappearance of the snowpack by 15 April. Both processing programs described in Section 2.2 are being used in the analysis. The alpha-numeric data printouts have been analyzed by hand; the procedure to apply the contour plotting program has been to reproduce selected temperature plots on transparent overlays at the appropriate scale for direct comparison with the snow boundaries observed in the corresponding HCMM visible channel images. The preliminary results of the analysis are as follows:

(a) 9 February 1979

Of the five Arizona cases, the maximum areal snow extent was observed on this date. Throughout the test area, the 0°C temperature contour correlates very closely to the observed snow boundary. Within the snowpack, minimum temperatures ranged from -5°C to -8°C.

(b) 15 Feburary 1979

Although the snow cover is substantially decreased on this date, the 0°C temperature contour still corresponds very closely to the snowline observed in the visible image. Minimum temperatures across the snowpack range from -4°C to -7°C.

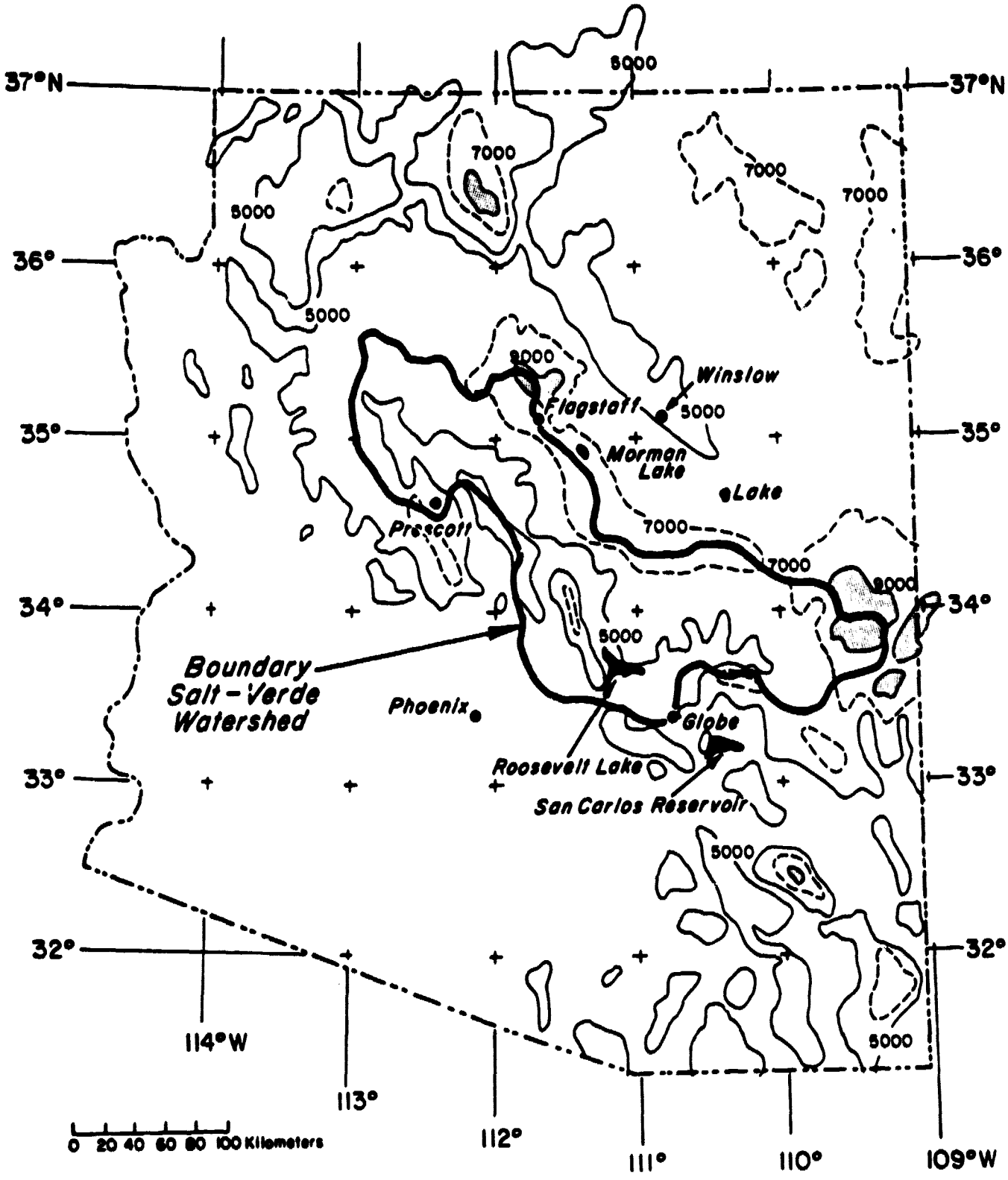

Figure 2 Map showing Salt-Verde Watershed, Arizona study area. Contours for 1500 m (5000 ft), 2100 m (7000 ft), and 2700 m (9000 ft) are indicated.

(c) 24 March 1979

The 0°C temperature contour is located slightly inside the observed snow boundary throughout the snowpack. Analysis of the digitized temperature printout shows that the +2°C temperature contour corresponds closely to the observed snow boundary of the main snowpack, whereas temperatures of the smaller, isolated snow boundaries of the higher elevation terrains located to the south, are closer to +4°C. The minimum temperatures within the snowpack range from -5°C to -6°C, which in most instances, correlate closely to the areas of maximum brightness observed in the visible image (i.e., areas of lesser or no forest cover).

(d) 4 April 1979

With significant melting having taken place since the previous observation, the snow boundary correlates closely to the +5°C temperature contour throughout the remaining snowpack. The 0°C isotherm is, however, located very close to the +5°C isotherm along the Mogollon Rim and also along the northern edge of the snowpack surrounding the Mt. Baldy area located in the eastern end of the Salt River Basin. The minimum temperatures within the snowpack in the Mt. Baldy area are in the -5°C to -7°C range; elsewhere, they range from -2°C to -3°C.

(e) 15 April 1979

The snow boundary along the Mogollon Rim corresponds closely to the +5°C isotherm, while the northern boundary of the snowpack in this region correlates more with the +7°C to +8°C isotherm. A small isolated pocket of minimum temperature (-1°C to -2°C) within the remaining snowpack corresponds to an area of maximum reflectance (non-forested) observed in the visible image. The temperature of the snow boundary located

west of Mormon Lake also appears closer to the +7°C to +8°C isotherm, whereas the temperature of Mormon Lake, which appears to be ice free, is -2°C to -3°C.

The evaluation of the analyses of the digitized HCMM data is continuing. The relationships between observed IR temperature and areas of rapid snow cover depletion are being examined. Further evaluations of the diurnal temperature range across the snowpack are also continuing. Initial examination of daytime maximum and nighttime minimum air temperatures at stations located within the snow covered area, shows that a daily melting-refreezing cycle is most likely occurring throughout much of the March to April period. Considerable ground-truth data such as snow course measurements, SNOTEL data, and miscellaneous ground observations are also being examined to determine the snowfall periods, as well as snow depths.

7.2 Sierra Nevada (California) Study Area

As discussed in Section 2.1, several good cases with both day and night HCMM coverage, have been selected for the Sierras study area. To date, the analysis has been concentrated on the 29-31 May 1978 case using the data listed in Table 2. A map indicating the area of the analysis, essentially in the Kings River Basin, is shown in Figure 3. Analysis of these data are being conducted at three levels: visual analysis of the HCMM imagery; analysis of the digital printout from the CCT's; and the use of the automated isotherm contouring program. The preliminary results are summarized below.

a. 29 May 1978 - Nighttime IR

The HCMM visible-channel images for 30 and 31 May indicate extensive snow cover throughout the southern Sierras. In the 29 May nighttime image, the areas of colder, high elevation snow cover appear as the darkest tones, with lighter tones present on the western slopes at lower elevations. When the image is compared with the digital printout, it was found that the boundary of the darkest tones corresponds to the -7°C isotherm, and the boundary of the lighter tones corresponds to the 0°C isotherm. The 0°C isotherm, plotted using the ERT automated contouring

TABLE 2

DATA ACQUIRED FOR THE SIERRAS STUDY
AREA CASE OF 29 MAY - 1 JUNE 1978

HCMM Imagery and CCT's

29 May 1978	Night IR
30 May 1978	Night IR
30 May 1978	Day VIS, Day IR
31 May 1978	Day VIS, Day IR

HCMR (U-2) Data

Flt 33	31 May 1978	Day
Flt 34	1 June 1978	Night

Other Satellite Imagery

Landsat	27 May 1978 (bands 5 and 7)
NOAA VHRR (IR)	30 May 1978
	31 May 1978

Other Correlative Data

Climatological Data Books
Upper Air Temperatures - 850 mb and 700 mb levels
Corps of Engineers Snow Survey Charts

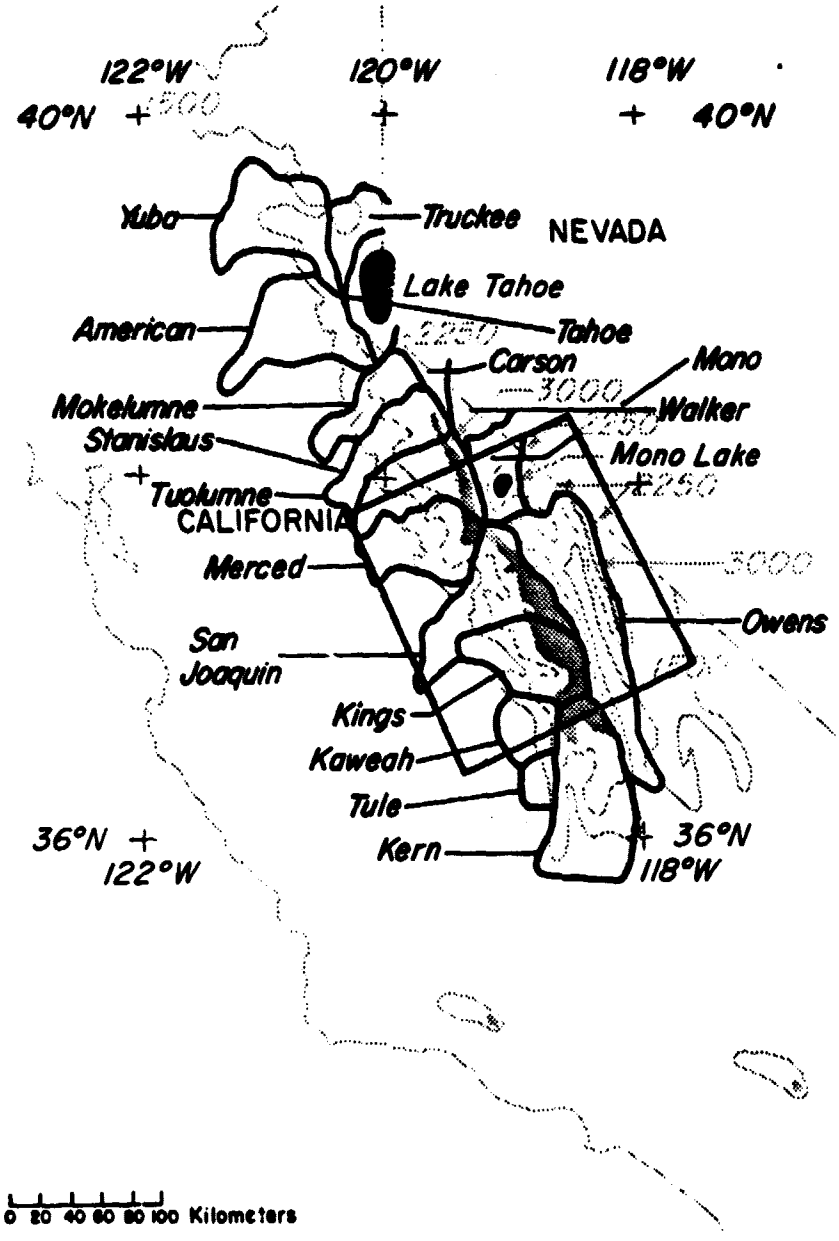

Figure 3 Map showing river basins in Sierra Nevada study area. Elevation contours are in meters. Area of analysis for 29-31 May case is outlined.

program, correlates very well with the snowline as seen on the daytime visible HCMM image. It appears, therefore, that the lighter tones may be the areas of lower elevation, melting snow, whereas the darker tone is associated with the colder snow at higher elevations.

b. 30 May 1978 - Nighttime IR

As was true the previous night, the 0°C isotherm on 30 May appears to depict the snowline boundary. In this image, however, the colder snow-covered areas appear to be saturated, obscuring details within the snowpack; since the saturated tone may be due to a problem with the processing of the HCMM print, we have requested that another image be produced for this date. Further analysis will be performed during the next reporting period.

c. 30 and 31 May 1978 - Daytime Visible and IR

Analysis of the imagery and digital products for these daytime passes indicates considerably higher temperatures. For both dates, the colder, more uniform snow cover at higher elevations is delineated by the 0°C contour; the overall snowline boundary as seen in the visible image is delinated by the +15°C contour.

d. Comparison of Daytime and Nighttime Temperatures

Prior to the availability of the day/night registered data, a preliminary analysis has been made from the day and night digital printouts to obtain an indication of the temperature range over the Sierras snowpack. Seven locations, including two lakes, were selected for the analysis of the temperature differences. These locations were identified on each of the four printouts (two nighttime and two daytime) and average temperature values were determined for a number of pixels within each area. The temperatures for each of the HCMM passes and the average differences between the daytime and nighttime passes are given in Table 3.

During the next reporting period, the day/night registered data will be analyzed to obtain a more accurate indication of the temperature differences. The measured differences will be examined to determine whether the day/night data provide a better indication of the snow

TABLE 3

HCMM TEMPERATURES FOR SELECTED LOCATIONS WITHIN SIERRAS STUDY AREA. TEMPERATURES ARE THE AVERAGE VALUES FOR SEVERAL PIXELS.

AREA	29 MAY 78 NIGHT IR	30 MAY 78 NIGHT IR	30 MAY 78 DAY IR	31 MAY 78 DAY IR	AVERAGE TEMPERATURE VARIATION FROM DAY TO NIGHT
A. MONO LAKE	+5.5°	-	+13.9°	+10.9°	-5.9°
B. LAKE CROWLEY	+3.8°	+4.6°	+14.1°	+12.8°	-9.3
C. WHITE MTS.	-7.5°	-9.1°	+9.0°	+7.5°	-16.5°
D. SNOWCOVER	-7.9°	-7.7°	-3.3°	-3.8°	-4.2
E. SNOWCOVER	-10.2°	-11.2°	-3.4°	-4.4°	-6.8
F. SNOWCOVER	-4.3°	-4.9°	+2.9°	-2.7	-4.2°
G. SNOWCOVER	-6.9°	-7.4°	-2.2	-4.8°	-3.7

conditions than could be derived from either daytime or nighttime thermal data, alone. The availability of HCMM passes on consecutive days will also permit an evaluation of the consistency of the data (coverage on consecutive days was not available for the Arizona study area). Moreover, U-2 supporting flights were made for all three Sierras cases selected for analysis (May 1978, July 1978, and April 1979); the U-2 data should provide a useful external calibration of the HCMM sensor.

Although the results obtained to date are only preliminary, the availability of good sequential HCMM coverage over the Sierras study area for the three separate cases will provide an excellent opportunity to evaluate the utility of HCMM thermal data for operational problems in snow hydrology.

8. FUNDS EXPENDED

With the approval of the additional funds, approximately 65 percent of the total available funds for the contract have been expended to date. It is anticipated that the investigation can be completed meeting all originally proposed objectives within the remaining funds and contract schedule.